Assimilation of Multi-Sensor Synoptic and Mesoscale Datasets: An Approach Based on Statistic, Dynamic, Physical and Synoptic Considerations

Xiaolei Zou

Dept. of Meteorology, Florida State University

404 Love Building, Tallahassee, FL 32306-4520

phone (850) 644-6025 fax (850) 644-9642 email zou@met.fsu.edu

Aw ard number: N00014-99- 1-0022

LONG-TERM GOALS

Our long-term goal is to contribute to our understanding of key elements for impro ving the 2 to 3 day forecast of P acific and A tlantic storms that strik e the w est coasts of U. S. and Europe b y observations and their assimilations. Of particular interest to us are the com bined effects of satellite data and in situ data (dropsondes, buoys, ships) on the initialization of a numerical forecast model to provide reliable objectiv e forecast guidance.

OBJECTIVES

Conducting data assimilation experiments using observ ations a vailable during F ASTEX and NORPEX, and a mesoscale forecast model. We focus on tw o technical and one scientific objectives listed below:

1. the best use of satellite data (TOMS ozone and water vapor winds), targeted dropson-des, and subjectiv e mesoscale analysis results.

2. the role of the bac kground term for mesoscale data assimilation.

3. the target observ ations in the presence of satellite data for improving 2 to 3-da y forecast of landfalling cyclones.

APPRO A CH

W e developed tw o 4D-V ar systems, one uses a large-scale global spectral model (the NCEP medium-range forecast model), and the other uses a mesoscale model (MM5). T echnical approac hes in volve:

1

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Assimilation of Multi-Sensor Synoptic and Mesoscale Datasets: An Approach Based on Statistic, Dynamic, Physical and Synoptic Considerations**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida State University,Department of Meteorology,404 Love Building,Tallahassee,FL,32306**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1. Four-dimensional variational data assimilation (4D-Var) with the Penn/State NCAR non-hydrostatic mesoscale model version 5 (MM5).

2. Adjoint sensitivity study.

3. Singular vector calculations.

4. Hand synoptic analysis.

The 4D-Var experiments assess the impact of various types of data, and the adjoint sensitivity and singular vectors provide additional insights into the key components for data assimilation and prediction, given the fact that the data are most likely insufficient.

Key individuals:

1. Drs. Zou, Xiao, and Pondeca: 4D-Var, adjoint sensitivity study, and singular vector calculations, analysis of numerical results.

2. Graduate students Mrs. Peng and Jang: idealized model and simplified problems.

3. Dr. Shapiro: Synoptic analysis.

WORK COMPLETED

A case study for the impact of TOMS ozone data on a FASTEX oceanic cyclone was completed. The column integrated ozone from the NASA Total Ozone Mapping Spectrometer (TOMS) were incorporated into a mesoscale prediction system through total ozone's correlation relations with model integrated potential velocity (IPV) quantities (Allaart et al., 1993).

An ozone advection equation was added to MM5, including the tangent linear and adjoint models. This will allow a direct use of TOMS ozone in 4D-Var using MM5.

A case study for the impact of targeted dropsonde data on a NORPEX oceanic cyclone was conducted using a version of NCEP 3D-Var system and a newly developed 4D-Var system (Zou et al., 1999).

The tangent linear and adjoint of a two-level hemispheric quasigeostrophic model (Whitaker and Sardeshmukh, 1998) were developed. This quasigeostrophic model and its linear and adjoint models will be used to assist our future work in evaluating theoretical ideas of cyclogenesis and some conceptual findings using complex models (MM5 and NCEP global model) to achieve a better synoptic and dynamic perspective of the real atmosphere regarding cyclone development, evolution and the associated mesoscale weather.

A case study for the impact of satellite-derived water vapor wind vectors (GMS winds) during NORPEX on the prediction of a major cyclone over the middle Pacific Ocean, which appears to have a controlling impact on the success of a 2-3 day forecast of a secondary cyclone downstream which made landfall on the west coast on the 23 February 1998.

RESULTS

1. The Impact of NORPEX Targeted Dropsondes on a Land-Falling Pacific Winter Storm Forecast Using NCEP 3D-Var and 4D-Var Systems.

   Impact of a set of NORPEX targeted dropsondes, deployed near a low center north of Hawaii on 29 January 1998, on the 48-h forecast of a Pacific winter storm development that later striked the U.S. west coast was assessed using NCEP (National Centers for Environmental Prediction) 3D-Var and 4D-Var systems. The 48-h forecast differences between 3D-Var with and without dropsondes were analyzed, followed by an analysis on the forecast differences between 4D-Var and 3D-Var with dropdsondes.

   During NORPEX, both NOGAPS and NCEP operational systems found negative impacts of these targeted dropsondes on the 48-h forecast of wind and surface pressure fields over the NORPEX forecast verification region (see Langland, et al., 1999). Our study indicates that the degradation on the 48-h forecasts was resulted from the fact that the NORPEX forecast verification region is not an adequate choice for the assessment of dropsondes' maximum impact for this particular case. The NORPEX targeted dropsondes during 00 UTC 29 and 00 UTC 30 January 1998 collected within a developing cyclone between Hawaii and Alaska made positive impacts to the 48-h forecast initialized at 00 UTC 30 January 1998 over regions where the control forecast did the worst. Assimilation of the targeted dropsondes using 4D-Var approach produced an even larger positive impact than the 3D-Var approach. These positive impact regions were located in the north eastern Pacific ocean, not over the NORPEX forecast verification region. While positive impacts of dropsondes are produced through a data assimilation procedure, forecast degradations are observed upstream and/or downstream of the positive impact areas. This could have caused the negative impact results in NOGAPS and NCEP operational systems. The occurrence of negative forecasting impacts areas near the positive impact areas could be associated with the sharp gradients of analysis errors near the boundaries of the dropsonde data region, which affected the forecast error growth and propagation.

   The only dropsonde experiments show that the 4D-Var analysis after one-day cycles of dropsonde data assimilation fits the conventional data better than that from 3D-Var. Comparing to 3D-Var, the analysis increments produced by 4D-Var due to the use of these targeted dropsondes showed a smoother distribution, a larger area coverage, and higher amplitudes.

2. Use of TOMS Ozone Data for the Prediction of FASTEX IOP-15.

   As column integrated ozone ("total ozone") correlates well with column integrated potential vorticity ("IPV"), total ozone data from satellites carrying the NASA Total Ozone Mapping Spectrometer (TOMS) were incorporated into the initial condition of a model prediction for a mature cyclone over the central Atlantic. The TOMS total ozone data were used in a framework of four-dimensional variational assimilation (4D-Var) with a mesoscale weather prediction model through total ozone's correlation relations with model IPV quantities. Assimilation of total ozone data produced significant differences in all three cyclones (FASTEX IOP-15, IOP-16A, and IOP-16) during a 3-day forecast over Atlantic ocean. The simulated cyclones with total ozone data had in general more rapid deepening than those in the control simulation without using

total ozone data. The former compared more favorably than the later to airborne dropsondes which were collected during FASTEX to document actual structures of the cyclone of FASTEX IOP-15. This study suggests that ozone measurements could be used for improving numerical prediction of weathers, especially for those in which potential vorticity plays an important role.

3. A Case Study of an NORPEX Oceanic Cyclone: Impact of Satellite-Derived Wind Vectors.

Satellite observations over data-sparse oceanic regions are expected to improve model initial conditions for the numerical prediction of landfalling cyclones in the west coasts. Our research effort will involve conducting 4-dimensional variational data assimilation (4D-Var) experiments which make use of these satellite data. The case chosen for this study is the two cyclones from the 1998 NORPEX experiment, which occurred during a time period from 12 UTC 19 to 12 UTC 24 February 1998. During 12 UTC 19 and 12 UTC 22 February 1998, a surface low near the east coast of Asia at 12 UTC 19 February 1998 developed into a mature cyclone (denoted cyclone A) in the middle Pacific ocean during the following 2-3 days. A secondary cyclone developed downstream of this mid-ocean cyclone on 00 UTC 22 and made landfall on the 23-24 February 1998 (denoted cyclone B). We study the forecast aspects of both cyclones, the upstream and downstream development, the essential information for a medium-range prediction of a mid-Pacific-ocean cyclogenesis which develops into a winter storm that strikes the U. S. west coast, and the potential impact of satellite-derived water vapor winds and column integrated ozone data on the model initialization and forecasts of these two cyclones. Before assessing the impact of satellite-derived water vapor winds and column integrated ozone data on the numerical simulation of these two cyclones, we conducted control forecasts, adjoint sensitivity studies and singular vector calculations to gain some insights into the key elements affecting the numerical prediction of these two cyclones.

A set of 48- to 120-h forecasts of both cyclones (cyclones A and B) indicates that comparing to NCEP large-scale analyses, both cyclone were predicted very well except when the model was initialized at 12 UTC 19 February 1998 (the 5-day forecast). The simulated development of cyclone A was much delayed, and the cyclone B at 12 UTC 24 February 1998 after landfall was hard to identify in the 5-day forecast experiment. Adjoint sensitivity and singular vector studies indicate that the numerical prediction of cyclone A is sensitive to the model initial condition at 12 UTC 19 February 1998 over Japan and south of Japan, and the 2-3 day predictions of cyclone B depend on how well the model states over the entire northern Pacific ocean are analyzed. The first experiment incorporating satellite-derived water vapor winds near 12 UTC 19 February 1998 showed a marginal impact on the 5-day forecast. Current study includes a detailed analysis of why the satellite winds made almost no impact, as well as a re-run of satellite wind data assimilation with an improved quality control.

4

IMPACT/APPLICATIONS

The TOMS ozone was, for the first time, used for cyclone predictions. Due to the good correlation of column integrated ozone and the IPV, TOMS ozone should play an important role in future observing system experiments such as THORPEX. They shall play a complementary role to other satellite data such as radiances which depend on the thermodynamics state of the atmosphere.

The dropsondes impact study indicates the dependence of data impact assessment on data assimilation approaches and on the selection of targeting and/or forecast verification regions.

Assimilation of satellite-derived water vapor wind vectors does not immediately provide improvement to the control forecast which fails to predict an oceanic cyclone development in the mid-Pacific. It may result from several reasons: (i) the quality control of data, (ii) the insufficiency of data coverage, (iii) the model errors in the assimilation model, and (iv) observational information on other state variables such as temperature and moisture.

TRANSITIONS

Our MM5 adjoint modeling system is in public domain.

RELATED PROJECTS

"Impact of radar, satellite and targeted *in situ* data on the hurricane forecasts near landfall", funded by NSF-USWRP under the project number ATM-9908939.

"Four-dimensional variational data assimilation and GPS data impact study using NCEP global model", funded by NSF under the project number ATM-9812729.

REFERENCES

Joly, A., D. Jorgensen, M. A. Shapiro, A. Thorp, P. Bessemoulin, K. A. Browning, J.-P. Cammas, J.-P. Chalon, S. A. Clough, K. A. Emanuel, L. Eymard, R. Gall, P. H. Hildebrand, R. H. Langland, Y. Lemaitre, P. Lynch, J. A. Moore, P. O. G. Persson, C. Snyder, and R. Wakimoto, 1997: The Fronts and Atlantic storm-track experiment (FASTEX): Scientific objectives and experimental design. *Bull. Am. Met. Soc.*, **78**, 1917-1940.

Langland, R.H, Z. Toth, R. Gelaro, I. Szunyogh, M.A. Shapiro, S. J. Majumdar, R. E. Morss, G.D. Rohaly, C. Velden, N. Bond, and C. H. Bishop, 1999: The North Pacific Experiment (NORPEX -98): Targeted observations for improved North American weather forecasts. Bull. Amer. Meteor. 80, 1363-1384.